Ore Fragmentation Modelling for the Evaluation of the Liberation Mesh Size

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Abstract. For mineral processing, an ore can be defined as the assemblage of useful mineral grains and gangue mineral grains. The first step of ore mineral processing involves crushing the material in order to achieve required mineral liberation. When it is achieved, in the ideal case, resulting fragments are formed: 1) only by useful minerals or 2) only by gangue minerals. This work consists to develop a numerical tool to determine the liberation mesh size of a given ore. With this aim, 1) a sample of the considered ore is modelled by a binary 3D image segmentation. Then, 2) a grinding process is modelled by a digital approximation of a Voronoi tessellation of the image, with random seeds. Each Voronoi cell represents a fragment of the ground ore sample. Fragments must meet several conditions so that they reproduce the characteristics of the crushing products in the mineral industry (e.g. the particle size distribution must follow a Rosin-Rammler law and the shape of the fragments must be close to spheres). This modelling allows obtaining the characteristics of the liberation mesh size. This is an important parameter to evaluate the feasibility of a mining project because the grinding operations are very expensive. This study would: 1) to evaluate and predict grinding costs from the bulk ore texture and 2) to provide an assessment tool downstream of the means of current observations and conventional analysis.

Keywords. Liberation mesh size, modelling, Voronoi cell, grinding.

1 Introduction

For mineral processing, an ore can be defined as the assemblage of useful mineral grains and gangue mineral grains. The first step of ore mineral processing involves crushing this material in order to achieve required mineral liberation. The liberation mesh size of a mineral is the size below which a mineral particle is completely liberated, that is to say only constituted of mineral species to value (Fig. 1). In general, the mineral industry tolerates 20% of mixed particle (i.e. fragments compounded of useful minerals and gangue minerals) (Blazy 1970) but this depends on the commodities and cases. Obtaining the liberation mesh size is an important parameter to assess the feasibility of a mining project. The grinding operations are very costly in energy. Up to 70% of the expensed energy in a mine can be used for grinding. The evaluation of the minerals characteristics (size of each particle, average of particle size, particle shape, present minerals, modal mineralogy, chemical composition of minerals, distribution of valuable element between minerals, texture (grain size, mineral association), degree of liberation by size, associated minerals in particles, ...) is important to achieve the best possible treatment (Kelly and Spottiswood 1982; Gy 1967). But a rigorous description of such a product is time demanding and costly in evaluation and characterization of the resource.

The purpose of this work is to evaluate a liberation mesh size estimation to quantify the particle size of the ore in the early stages of mineral exploration, i.e. at the time when the samples of the studied mineralization have a volume at most some cubic decimeters.

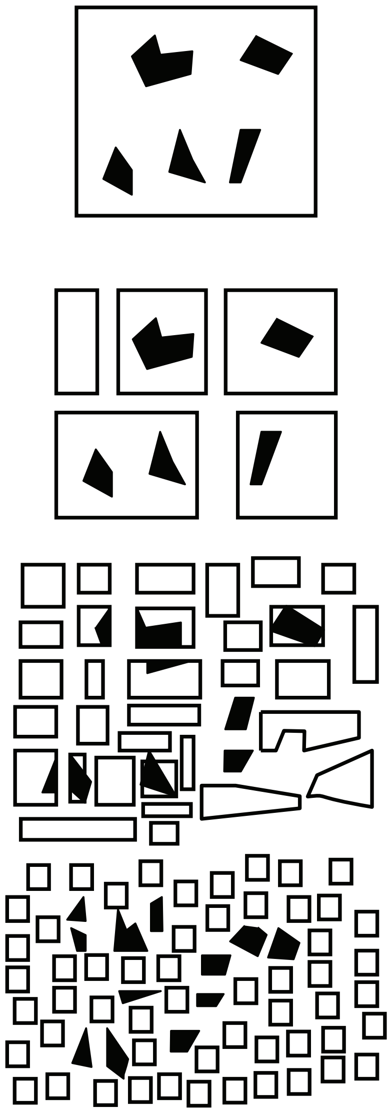

Figure 1. Schematic ore fragmentation. The top image represents the bulk ore with useful minerals (in black) and gangue minerals (in white). The Three other images correspond to successive stages of fragmentation. Down, the ideal liberation of the useful minerals is achieved.

2 An approach for the modelling of liberation mesh size

Theoretical studies on the particle size of fragmented ore have highlighted the role of some parameters: shape factor, particle size distribution parameter, and texture of the initial product (i.e. bulk ore). A model of mineral liberation must take into account these characteristics. In other words, we state that if these characteristics evaluated on a numerical model are the same as that of a real crushed sample, this grinding model can be considered as satisfactory.

2.1 Shape factor

The shape factor is defined using the opening d of the smallest square mesh of the sieve capable of passing the fragment (Gy 1967). For ground products of the mineral industry, the shape factor (f = volume of the particle / d^3) measures the deviation from a cubic shape (Gy 1967). The study of many crushed ores showed that for a fragment, f is usually close to 0.5 (Gy 1967), i.e. the shape of the fragments is close to sphere. In addition, the f parameter varies little from one mineral to another and for a given mineral, of a size to another (Gy 1967).

2.2 Particle size distribution parameter

It is useful to adjust the experimental data of the particle size measures to an analytical function. It consists in building a curve from mathematical functions and adjusting the parameters of this function to be closer to the experimental curve. These parameters will be handled so that the calculations with this function were easier than the calculations on experimental data. Different models are used for adjusting the particle size distributions (Allen 1981; Peleg 1996; Ouchterlony 2005). The most widely used model for the case of particle size data from the mineral industry is the Rosin-Rammler function. The model of Rosin-Rammler can be considered as a Weibull distribution (Patel 1976; Outal 2006).

The particle size distribution parameter was defined as $g = d_{95} / d_5 > 4$ for many ores (Gy 1967).

2.3 Texture of the bulk ore

In this study, we developed a new approach to model ore grinding and determine the liberation mesh size. Ore images were obtained by X-ray microtomography which is a nondestructive imaging technique that provides 3D images of the interiors of materials (e.g. Rozenbaum and Rolland du Roscoat 2014). Each voxel in the 3D image was characterized by its grey level (ranging from 0 to 255 for an 8-byte image), which depended on the X-ray attenuation coefficient of the element. This attenuation coefficient depends on material density and on the atomic number of the components. In other words, at each space position of the 3D image, a grey value corresponds to a given phase (gangue and useful minerals).

Prior to model grinding, the different phases have to be distinguished that is known as the segmentation step. Segmentation is the process of partitioning the grey level voxels of the 3D image into distinct phases. Due to noise inherent to image acquisition, a preprocessing step was firstly applied consisting in a noise reduction (filtering). This preprocessing step was followed by a thresholding step (see Le Trong et al. 2008 for more details). As a result, the segmented 3D image is transformed to a binarised image as shown in Fig. 2. The ore used for this study is hosted in Aptian carbonate formations of the northern Spain from Reocin (MVT deposit type). Therefore, in white is represented dolomite and marcasite (gangue phase) and sphalerite and galena in black (useful minerals).

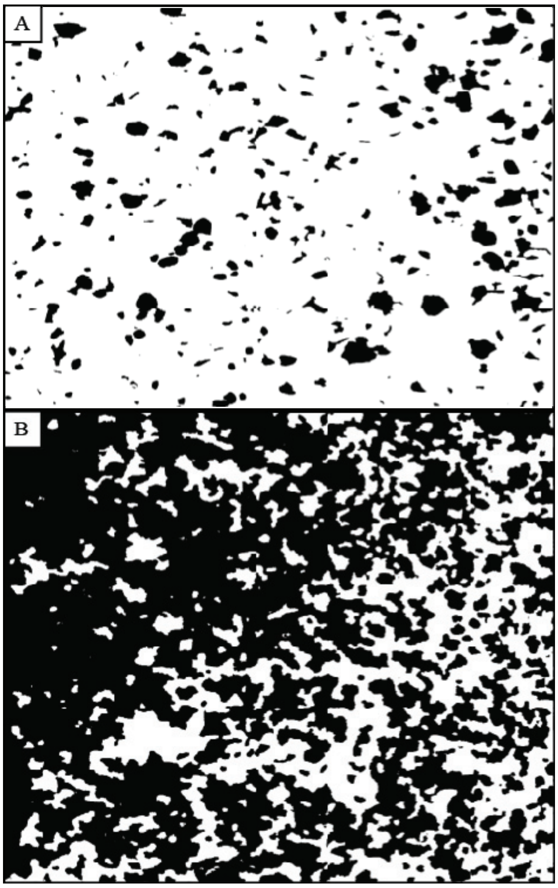

Figure 2. 2D images extracted from 3D binarised images. **A.** image poor in useful mineral; **B.** image rich in useful mineral. The gangue phase is in white (dolomite and marcasite) while the useful mineral is in black (sphalerite and galena).

2.4 Fragmentation model

Outal (2006) has observed that its processed image shows particles of a fragmented rock whose particular shape can be assimilated to a Voronoi diagram (Fig. 3). Therefore, for this study, we propose to model grinding results by 3D Voronoi cell paving. Voronoi diagrams represent distance relationships between objects. All Voronoi regions are in shape of polyhedra and convex (Fig. 3) that looks like fragments from grinding in mineral industries. The grindability of all the ore component phases is considered identical.

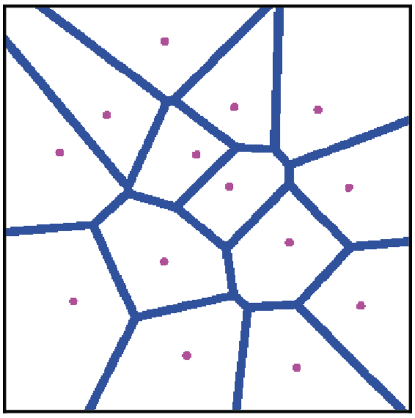

Figure 3. An example of 2D Voronoi cells representation of polyhedron and convex shape from germs (represented by the red points).

3. The proposed liberation model

To model the liberation mesh size, we numerically grind the 3D binarised image of bulk ore with 3D Voronoi cells up to the liberation mesh size (Fig. 4). For this, we must take into account: 1) the texture of bulk ore; 2) grinding; 3) the edge effects.

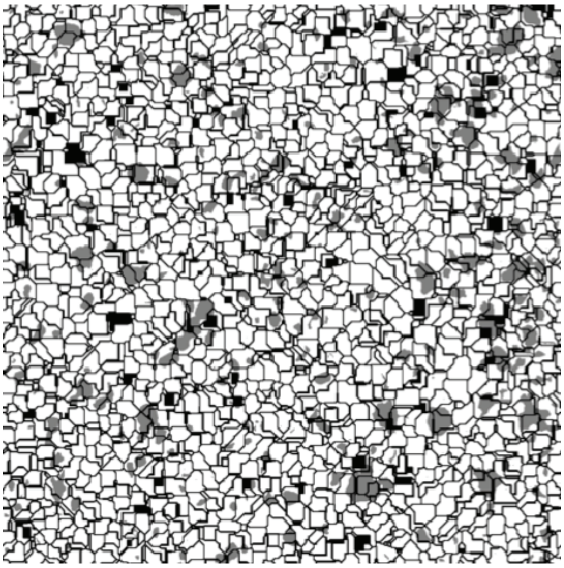

Figure 4. Grinding modelisation with Voronoi cells. For sake of clarity only a 2D image extracted from the 3D image is represented here.

To build the Voronoi cells, a set of random points is generated within the 3D binarised image (Fig. 5). These points are called germs. Then, a computer code developed by authors allows Voronoi cell formation (cells expand until they touch other cells in each direction in space). This simulates the grinding as each dilated cell forms a fragment. For each fragment, we get its size, its useful mineral content and its shape factor. Note that the density of germs controls the shape of the granulometric curve. The edge effect is controlled by removing all the cells that are on the boundary of the image.

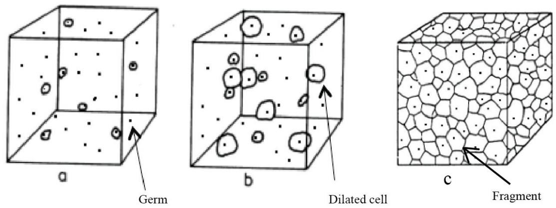

Figure 5. Building of Voronoi cells: a) germs generated within the 3D image; b) cells expanded; c) cells touching other cells and forming fragments.

From a real bulk ore, we choose two binary 3D images: one rich in useful mineral and the other one poor in useful mineral (Fig. 2). For each image, we generate several quantities of germs (10000, 50000, 100000 and 200000) (Fig. 5). For each amount of germs, we study the size distribution of all fragments and the size distribution of fragments having at least 80% of useful mineral (obtaining practical liberation mesh size) (Fig. 6). These distributions are, in fact Rosin-Rammler distributions.

To validate our breakage ore model, we will compare the results of the modelling work with real measurements on mining product during grinding in the Reocin mine. This will validate the model or change it if does not describe well enough the reality.

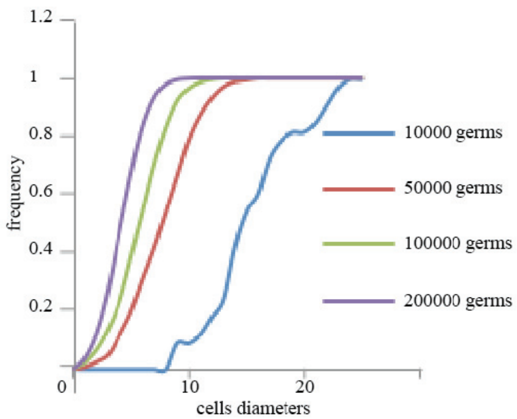

Figure 6. Comparison of size distribution of fragments having at least 80% of useful mineral. Cells diameters are in voxels (modified after Ngassa Tankeu 2014).

4. Conclusion

The purpose of this study is to make an estimate of the liberation mesh size with the data available in the early stages of mineral exploration. This is to allow estimating the energy cost of grinding to liberation mesh size and provide an assessment tool downstream current means of observation (HyChips, Qemscan, X-ray tomography) and conventional analysis. For this, we simulated a bulk ore grinding from Voronoi cells. The particle size distribution of these fragments is similar to a Rosin-Rammler distribution. The results are encouraging.

The ultimate goal of this study is to build a 3D diagram in which the particle size curve and for each size fraction, the liberation degree within the particle size fraction, are plotted.

An opportunity of improvement for this work is the introduction of preferential fragmentation i.e. the grindability of the different phases constituting the ore is no longer considered to be identical.

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